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Flow characteristics of air in square duct using delta wing vortex generators☆

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Summary Performance improvement in terms of improving heat transfer coefficient and reducing pressure drop becomes essential in heat exchange applications and a large number of methods for reducing pressure drop exist in the literature and the present work is an investigation on use of delta wings as vortex generators for reducing pressure drop. Methodology includes air from a blower entering the test section through orificemeter and differential-micro manometer to measure the flow rate and pressure drop across the test section. Depending upon the pressure drops, friction factors for smooth and rough surface of the duct are estimated. The effect of geometrical parameters of delta wing and duct aspect ratio on friction factor ratios are reported Based on Reynolds number in the range of 8000—24000. The geometrical parameters of vortex generators varied in this study were the pitch-to-vortex generator height ratio (p/e), vortex generator height to duct hydraulic diameter ratio (e/Dh), aspect ratio of vortex generator (ar). Results are reported for $0.1 < e/Dh < 0.5$, $p/e = 4,8,12,16$, $(ar) = 1.6,2.3,4$, $N = 1$ in ducts having aspect ratio $AR = 1$, Detailed friction factor analysis for Re 8000—24000 has been presented for different configurations of vortex generators used in the square duct. The experimental results of the present study for friction factor in smooth square duct matches well with values taken from formula proposed by Blasius. The friction factor ratio increases with increase in e/Dh value, which may be attributed to increased blockage of the flow passage. For a given p/e, increasing e/Dh ratio for the same (ar) has the effect of increasing circulation strength and core size of the vortex thereby offering more resistance to flow that results into a higher friction factor ratio. The results have been presented in the form of the friction factor ratio of the roughened and smooth ducts operating at equal Reynolds numbers. Semi-empirical correlations for friction have been developed on the basis of available methodologies for rough walls.

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Introduction

An increase in the distance between the delta wing tip and bottom surface of the duct have been made to obtain more friction factor ratio's that is a higher pressure drop which is used to analyze the efficient heat transfer surfaces for non-circular flow passages. As technology progresses and efficiency requirements increase, greater emphasis must be laid upon gas turbine development to meet the challenge of maximizing heat transfer at minimum pressure drop. Many researchers have studied extensively the heat transfer applications in engineering industry that involves mixed convection and internal flow in non-circular channels and ducts such as square, rectangular, trapezoidal, polygonal and triangular (Katti et al., 2013). The hydrodynamics and thermal fields were strongly related to each other in these channels. This paper deals with experimental results of hydrodynamics inside a square duct. Several methods are known to enhance the convective heat transfer in heat exchange equipment. Turbulence promoters or delta wing vortex generators are often used to manipulate the flow field and they can provide a beneficial effect on the thermal performance (Jacobi and Shah, 1995). Use of turbulent creators to increase the convective heat transfer will also increase pressure drop because of increasing friction factor when pressure drop increases it requires more pumping power to pump the working fluid. So that this paper reported that optimal distance between the delta wing tip and bottom surface of the duct to improve the convective heat transfer with minimum pressure drop.

Experimental set up

1. Air blower 2.Controle valve 3.Micro deferential manometer 4.Square duct 5.Pressuretap 6.orificemeter 7.U tube manometer 8.Delta wing vortex generator

Experiments are performed in an experimental set-up as depicted in Fig. 1. The experimental system consists of a square channel. Blower sucks the air, air enters into the test section through a valve, which controls the flow through the test section. An orificemeter used for the flow rate measurement. A simple U-tube manometer is used for the measurement of differential pressure head across the orificemeter. A differential manometer with a combination of water and benzyl alcohol as the manometric fluids is connected across the test section to measure the pressure drop across the test section. Two pressure taps give value of pressure of the test section where pressure measurement is required. And channel roughened with delta wing vortex generators.

Table 1 Validation table of friction factor vs Reynolds numbers.

Reynolds number	*f*	*fs*
8000	0.0082	0.007611
12000	0.0074	0.007013
16000	0.00637	0.006623
20000	0.0061	0.006375

From the Table 1 friction factor vs. Reynolds number for the smooth square channel '*f*' means actual friction factor obtained from experiment '*fs*' is the theoretical friction factor obtained from the Blasius equation for the smooth channels. From this table, we can say that the experimental results for friction factor in smooth square duct reasonably agree well within ±7 and ±4% values estimated from correlation proposed by Blasius ($fs = 0.046Re^{(-0.2)}$).

Data reduction

Pressure difference between two taps of the square ducts *(ΔP)*, experimentally determined friction factor in the test section *(f)*, friction factor obtained from Blasius equation *(fs)*.

$$\Delta P = \rho 2gh[1 - (\frac{\rho 1}{\rho 2}) + \{(\frac{a}{A}) * (\frac{\rho 1}{\rho 2})\}] \quad (1)$$

$$f = \frac{\Delta P}{(4L/Dh)(\rho av2/2)} \quad (2)$$

$$fs = 0.046Re^{(-0.2)} \quad (3)$$

In the above calculations, air properties corresponded to mean air temperature. On the basis of error analysis, the uncertainties at different *Re* have been estimated to be ±7 and ±4% in friction factor by using Blasius equation.

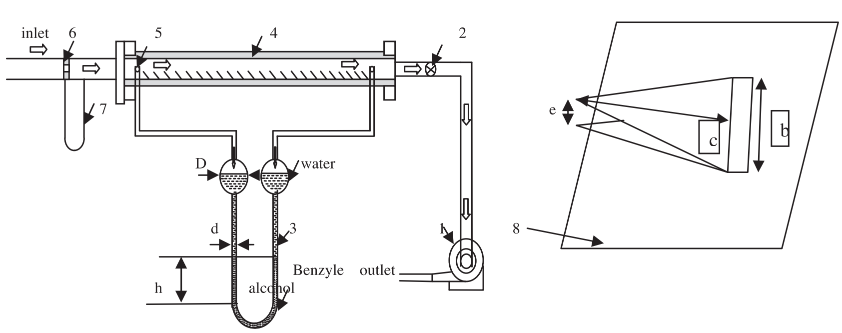

Figure 1 Experimental set up with delta wing vortex generator.

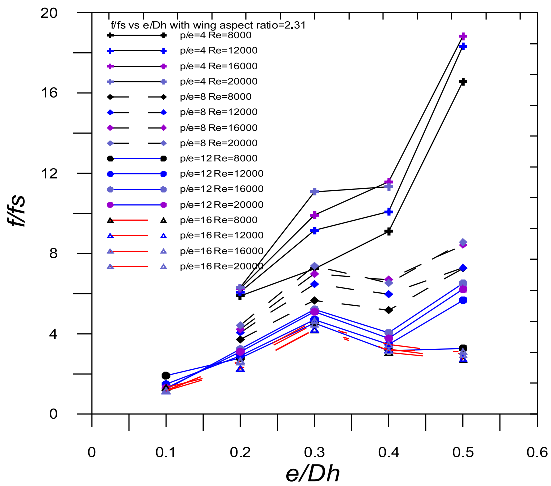

Figure 2 *f/fs* vs *e/Dh* with aspect ratio of wing 2.31.

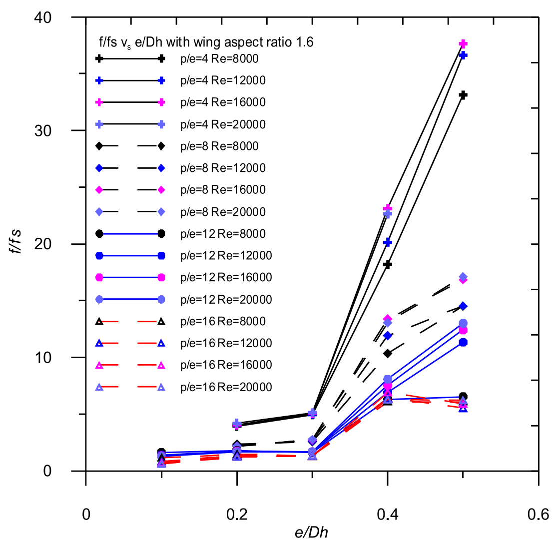

Figure 3 *f/fs* vs *e/Dh* with aspect ratio of wing 1.6.

Result and discussion

Influence of the vortex generator height to duct hydraulic diameter ratio (*e/Dh*)

In order to study the Influence of the vortex generator height to duct hydraulic diameter ratio *(e/Dh)* on friction factor ratio *(f/fs)* for the square duct having Delta wing vortex generator the vortex generator height to duct hydraulic diameter ratio *(e/Dh)* set as 0.1, 0.2, 0.3, 0.4, and 0.5 and Reynolds number ranges from 8000 to 20000. The Figs. 2 and 3 and show influence of configuration of delta wing vortex generator having aspect ratio 2.31 and 1.6 on friction factor ratios for the different Reynolds number from these figures we can observe that the friction factor ratio increasing with increasing *e/Dh* value because *e/Dh* increases delta wings offers more resistance to the flow air through the duct and also from those figures the friction factor ratios with different *e/Dh* values decreasing with increasing Reynolds number because when Reynolds number increases the effectiveness of air vortices formed due to wings inside the duct reduces.

In Fig. 2, the value of friction factor ratio at *e/Dh* = 0.4 is lesser compare to the value of friction factor ratio at *e/Dh* = 0.3 and 0.5 for different Reynolds numbers because when *e/Dh* = 0.4 the air vortices formed in the duct are broken so that wings offers lesser resistance to flow of air therefore friction inside the duct is reduces.

Influence of the vortex generator aspect ratio

The values of friction factor ratios for the Fig. 3 are more compare to Fig. 2 or we can say the friction factor ratios of wings having aspect ratio 1.6 are more compare to wings having aspect ratio 2.31 because aspect ratio of wing (ar) = 2b/c it means chord length of wing 'c' is inversely proportional to the aspect ratio of wing so chord length of wing having aspect ratio 1.6 is more therefore the delta wing vortex generator having aspect ratio 1.6 offers more resistance to the flow of air because this the values friction factor ratios in that configuration of the wing are more.

Conclusion

Friction factor characteristics in the square channel with the delta wing vortex generators (DWVGs) are investigated for Reynolds numbers ranging from 8000 to 24,000. The effects of the Vortex generator height to channel hydraulic diameter ratio *(e/D_h)* on friction factor in the square channel is explained in this paper. The concluding remark is increasing e/D_h friction factor ratio increases up to 30—60% from lowest e/D_h to highest e/D_h it means the pressure drop increases in the channel with increase in generator height to channel hydraulic diameter ratio (e/D_h). But by the use of delta wing configuration *e/Dh* = 0.4 in square duct with aspect ratio (ar) 2.31 we can optimize the friction inside the duct.

Dh Hydraulic diameter of test section	*fs* Theoretical Friction factor in a four- sided Smooth duct
b Vortex generator base	p Pitch
c Chord length	ρa Density of air
e Height of Vortex generator tip above.	$\rho 1$ Density of water
f Experimental value of friction factor	$\rho 2$ Density of benzyl alcohol

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